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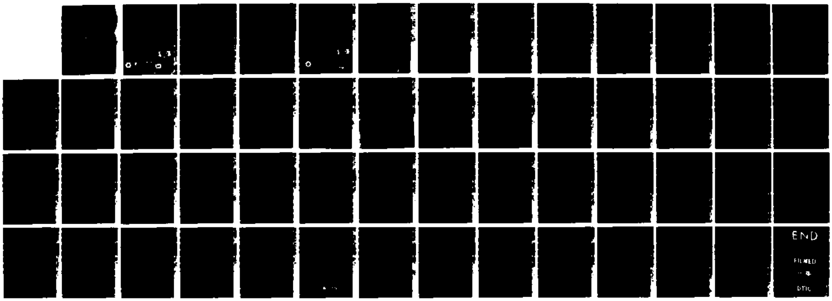

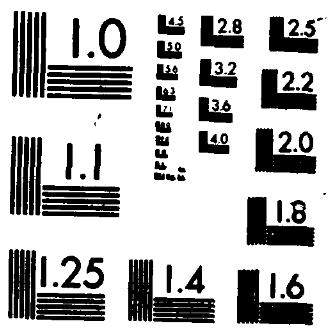
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OLD DOMINION UNIVERSITY RESEARCH FOUNDATION

APPLIED MARINE RESEARCH LABORATORY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

WATER QUALITY MONITORING AT THE NORFOLK DISPOSAL SITE

By

Raymond W. Alden, Principal Investigator,

Joseph H. Rule, Suzanne S. Jackman, and

Arthur J. Butt

Supplemental Contract Report.
For the period ending September 1984

Prepared for the
Department of the Army
Norfolk District, Corps of Engineers
Fort Norfolk, 803 Front Street
Norfolk, Virginia 23510

Under
Contract DACW65-81-C-0051
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Overall water quality is excellent at NDS. The effects of depth, season and geographic location were statistically defined for each of the water quality parameters. Differences between the water quality and NDA and that found in surrounding waters were seldom observed. Chesapeake Bay plume influence is observable (particularly in southwest portion of the study area).

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WATER QUALITY MONITORING AT THE NORFOLK DISPOSAL SITE

By

Raymond W. Alden[1], Joseph H. Rule[2], Suzanne S. Jackman[3], and Arthur J. Butt[4]

INTRODUCTION

The continual dredging of navigational channels in major seaports is essential to maintain shipping access. However, the disposal of potentially contaminated dredged materials raises environmental issues. Current methods for dredged material disposal include: landfill, onshore, and open ocean disposal. Available land for onshore and landfill disposal is often at a premium in the industrialized, urban seaport and may present a variety of social, economic, and ecological problems.

Recently, renewed interest has been generated in the feasibility of the open ocean disposal of dredged materials. Currently, dredged materials from the Hampton Roads Harbor area are being disposed at the Craney Island containment facility. However, Craney Island has a finite capacity in its current configuration. An open ocean disposal site designated the Norfolk Disposal Site (NDS) is being considered as an alternative for some of the Norfolk Harbor system dredged material. The present ongoing study involves the monitoring of baseline water quality characteristics at the NDS. This study was undertaken to characterize the magnitude of natural spatial-temporal variability of various ecological parameters and to develop a series of multivariate statistical models to be used as an "early warning system" in historic trend assessment studies. This report presents the results of a three year baseline water quality program at the NDS.

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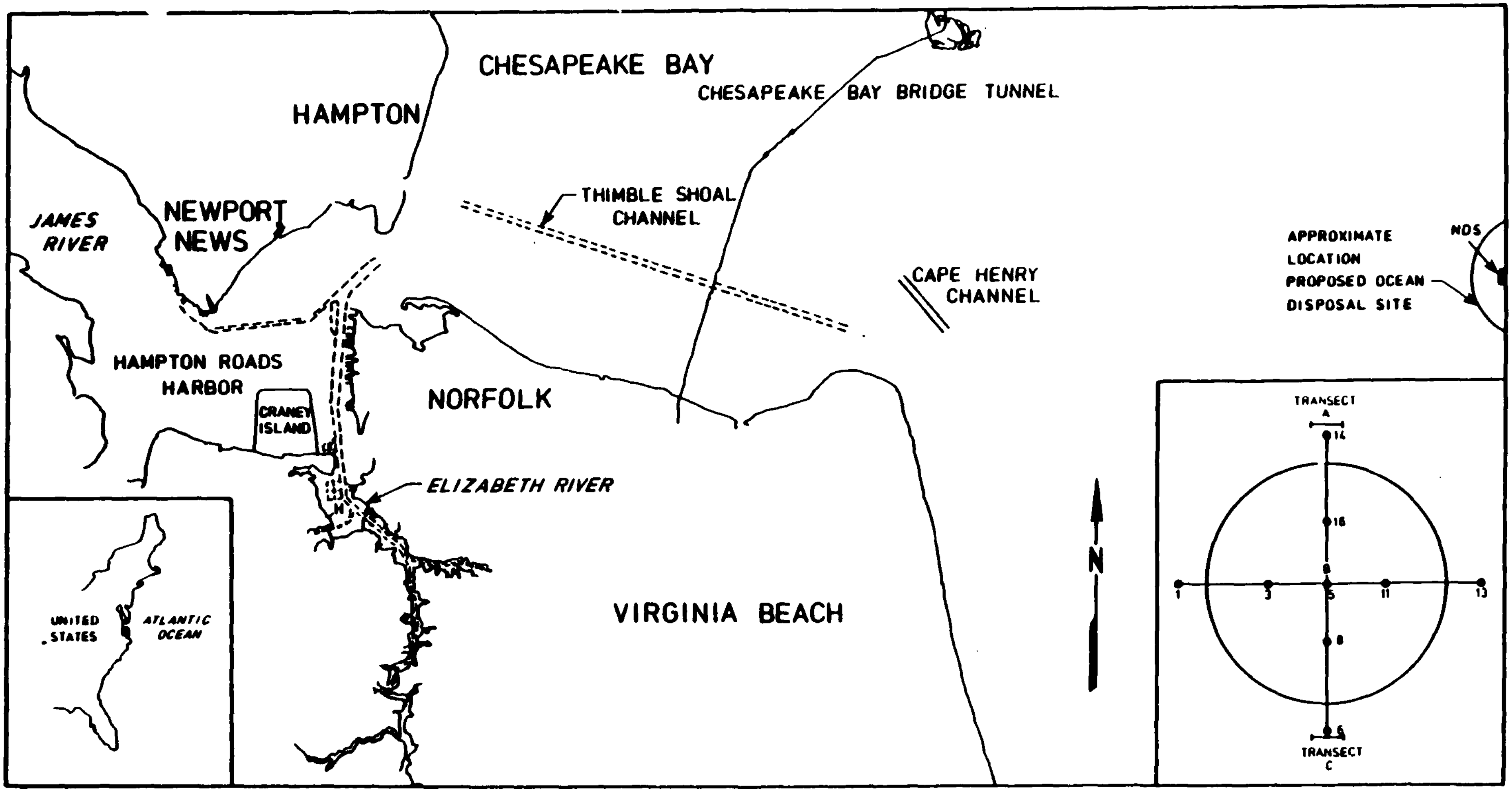
STUDY AREA

The proposed Norfolk Disposal Site delineated as a circle with a 4 nm (7.4 km) radius is located beyond the 10 fathom contour line approximately 27 Km east of Chesapeake Bay mouth (Figure 1). The water flow pattern in this region of the middle Atlantic Bight is variable (Beardsley and Boicourt, 1980; Boicourt, 1981). The flow pattern on the continental shelf is typically southward (Bumpus 1973) with the shallower inner shelf dominated by wind driven forces (Boicourt and Hacker, 1976; Boicourt, 1981). Near estuarine influences, the flow patterns are more complex. More specifically, the flow pattern at the Chesapeake Bay mouth/continental shelf interface and seaward is very dynamic. Circulation at the interface is in response to the synergistic interactions of river run-off, vertical decoupling at the pycnocline, wind and tidal prism patterns (Boicourt and Hacker, 1976; Wang, 1979; Boicourt, 1981; Johnson et al., 1983).

Short term disruptions to routine flow patterns around the Bay mouth are common. Wind forcing of the shelf waters affects the nontidal flow through the Bay mouth. Bottom waters further than 20 km east of the Bay mouth were reported to flow towards the Bay with prevailing southerly winds during the summer, whereas the inner shelf surface waters showed a northward drift (Boicourt 1981). However, strong winds can produce outflow or inflow surges. Boicourt (1973) reported a 10% volume reduction in Chesapeake Bay over 48 hours resulting in an outflow surge extending far offshore.

Nine stations were monitored for water quality parameters at the proposed disposal site from 1981 through 1983 (Figure 1). A central station, #5 (36° 59' N and 75° 39' W) and eight additional stations were located at the cardinal points to station 5: four stations (16, 11, 8, 3) were located at a 2 nm (3.7 Km) radius from the center and the remaining four (14, 13, 6,

Figure 1. Location of the proposed Norfolk Disposal Site (NDS).


CHESAPEAKE BAY
CHESAPEAKE BAY BRIDGE TUNNEL
HAMPTON
NEWPORT NEWS
JAMES RIVER
THIMBLE SHOAL CHANNEL
CAPE HENRY CHANNEL
APPROXIMATE LOCATION PROPOSED OCEAN DISPOSAL SITE
NOS
HAMPTON ROADS HARBOR
CRANEY ISLAND
NORFOLK
ELIZABETH RIVER
VIRGINIA BEACH
N
UNITED STATES
ATLANTIC OCEAN
TRANSECT A
TRANSECT C
14
16
1
3
5
11
13
8
6

1) were placed 1 nm (1.85 Km) beyond the NDS boundary or 5 nm north, south, east and west of center. The depth of NDS varied from 16 m (52 ft) to 26 m (85 ft).

METHODS AND MATERIALS

Water quality monitoring at NDS stations was dependent upon ship availability; however, all the stations were sampled for each season of the three year study (1981 - March, April, June, August and October; 1982 - January, April, August, and October; 1983 - February, April, July and December). Duplicate water samples were collected at 1 m below the surface and 1 m above the bottom in 5 or 8 l teflon-lined go-flo bottles. Aliquots were withdrawn from the go-flo bottles and nitrite (NO_2), nitrate (NO_3), total Kjeldahl nitrogen (TKN), orthophosphates (OPO_4) total phosphorus (TP) chemical oxygen demand (COD), pH, turbidity, suspended solids, volatile nonfilterable residue (VNR), and chlorophylls (a, b, c, phaeophytin a) were determined.

Field measurements of temperature (^{o}C), salinity ($^{o}/oo$), and dissolved oxygen (DO) were monitored at a surface and near bottom depth at each station by portable field meters. The DO meter was calibrated against a Winkler titration.

Chlorophyll a, b, c and phaeophytin a were measured and calculated by the UNESCO method (Strickland and Parsons, 1974). Suspended solids and volatile nonfilterable residues were determined by drying the samples to a constant dry weight and subsequently ashing the samples (APHA, 1975).

Nitrate levels were determined by the Brucine metnod (APHA, 1975) in

1981 and 1982, and by cadmium reduction (APHA, 1975) in 1983. Nitrites were analyzed by sulfanilic acid and (APHA, 1975). Total and orthophosphate concentrations were determined by ammonium molybdate and potassium antimonyl tartrate reactions with orthophosphates. Samples analyzed for total phosphates were first digested by the persulfate method to oxidize all forms of phosphorous to the ortho phosphate form (APHA, 1975). Total kjeldahl nitrogen and ammonia samples were steam distilled and processed by nesslerization (APHA, 1975). Chemical oxygen demand (COD) was performed by a modified Hach (1981) procedure in which samples were diluted to 20 $^0/_{00}$ salinity and treated with $HgSO_4$ to reduce chloride interference.

STATISTICAL ANALYSIS

Computer based, multivariate analytical techniques were employed to characterize the spatial-temporal characteristics of NDS under baseline conditions. A series of complementary multivariate statistical approaches were taken. Discriminant analysis (Klecka, 1975) was employed to determine whether any significant patterns could be detected in the water quality data set with respect to groups selected a priori to the collections. The groups were selected to examine patterns with depth (e.g., surface versus bottom values) and with season (e.g., month to month changes).

In order to examine significant patterns detected by the discriminant analysis in more detail, multivariate analysis of variance (MANOVA) models (Hull and Nie, 1981) were employed to test the same spatial-temporal effects. Since the discriminant models are often overly sensitive in terms of indicating "significant" differences even when they do not occur, the MANOVAs were considered to be the definitive tests of significant patterns

(see accompanying report entitled, "Statistical Significance in Baseline Monitoring" for a more detailed discussion). The MANOVAs were also employed to test for any unusual patterns at NDS under baseline conditions (see discussion of the season-area interaction model in accompanying report, ibid). For each effect, the MANOVAs tested for significant patterns in all variables in both the multivariate models and in univariate analogs to ANOVA.

The third step in the analytical procedure was to employ principal components analysis (PCA) (Kim, 1975) to reduce the data set into a relatively few factors which retain most of the information concerning significant patterns. These factors can then be plotted for data presentation (e.g., ordination).

Thus, the analytical regime included a preliminary screening step (discriminant analysis), a statistical testing step (MANOVA), and a data reduction/presentation step (PCA ordination). The multiple model approach to data reduction, analysis, and interpretation has been selected because it is recognized that environmental data sets are unlikely to conform exactly to all of the assumptions of multivariate statistics, even when transformations (e.g., logarithmic transformations were applied to all data except pH) have been applied in an attempt to "normalize" the data. Therefore, it is felt that if a number of statistical models with different mathematical approaches and assumptions all indicate similar patterns to be significant, the trend can be considered to be important. A second conservative convention was adopted in the interpretation of "significant" trends; only those relationships that exhibited a high degree of significance (i.e., low α level) were emphasized so that the robustness of the tests would be expected to overcome deviations from multivariate normality. This convention is espe-

cially appropriate for monitoring studies, where numerous statistical tests may be run over time and Type I errors (i.e., false alarms) would be likely to occur by chance alone if a lower level of significance was accepted. Therefore, in the interpretation of the findings, only those trends that are highly significant ($p < 0.001$) or recurrent are emphasized.

In addition to the characterization of spatial-temporal baseline patterns, the water quality program at NDS involved the development of statistical techniques for the estimation of levels of "minimum detectable impacts" (MDIs): those levels of change in any given variable which would be required to define a statistical difference during trend assessment studies. The philosophical concept of the MDIs and the methods for the calculation of various MDI models were detailed in the accompanying report (ibid). The MDIs were calculated for each variable for single samples, and for data sets (representing data from a single post-impact cruise) employing seasonal, baseline, and interaction models.

RESULTS AND DISCUSSION

Spatio-Temporal Patterns

There were significant changes in water quality between each consecutive seasonal cruise at the NDS study area (Table I). Except for the Fall-Winter period of 1982-83 (October and February), there were significant differences between the surface and bottom water samples. Thermal stratification was maximum during the Summer (i.e., an average of approximately 10°C difference between surface and bottom temperatures), and virtually disappeared during the colder months (Figure 2a). Salinities were generally

TABLE I

Summary of MANOVA tests of depth and seasonal effects. Multivariate and univariate effects significant at the α=0.001 level are indicated.

	1981									
	March		April		June		August		October	
Parameter	Depth	Season	Depth	Season	Depth	Season	Depth	Season	Depth	Season
Multivariate model	*	N/A	*	*	*	*	*	*	*	*
Temperature	S	"	S	↑	S	↑	S	-	-	↓
Salinity	-	"	B	-	B	↓	-	↑	B	↑
pH	S	"	-	-	-	-	-	↑	-	↓
D.O.	-	"	B	↓	B	↓	S	↓	-	↑
C.O.D.	-	"	-	↑	-	↓	-	↑	-	-
Turbidity	B	"	B	↓	S	-	B	↑	B	↓
S.S.	B	"	-	-	-	-	-	-	B	-
Volatile residue	-	"	-	↑	-	↓	-	↑	B	↑
NO_2	-	"	-	-	-	-	-	-	-	-
NO_3	-	"	-	-	-	-	-	-	-	-
NH_3	-	"	-	-	-	↓	-	-	-	-
TKN	-	"	-	-	-	-	-	-	-	-
OPO_4	-	"	-	-	-	-	-	-	-	-
TP	-	"	-	↓	-	-	-	↑	-	↓
Chlorophyll a	B	"	B	↓	-	↓	-	↑	B	↑
Chlorophyll b	-	"	-	↓	B	↑	-	-	-	-
Chlorophyll c	B	"	-	↓	-	↑	-	↑	B	↓
Phaeophytin	-	"	-	↓	B	-	-	-	-	-

Notes:
* = Multivariate model significant for the effect (depth or season)
S = Surface values are significantly greater
B = Bottom values are significantly greater
↑ = Values increase significantly from previous cruise
↓ = Values decrease significantly from previous cruise
- = No significant pattern for the effect

TABLE I (continued)

Parameter	1982 January Depth	January Season	April Depth	April Season	August Depth	August Season	October Depth	October Season
Multivariate model	*	*	*	*	*	*	-	*
Temperature	B	↓	S	↑	S	↑	-	-
Salinity	B	↓	B	↓	B	-	-	↑
pH	-	↑	-	↓	-	↑	-	-
D.O.	-	↓	-	↑	B	↓	-	-
C.O.D.	-	↑	-	↓	B	-	-	↑
Turbidity	-	-	-	-	-	-	-	↑
S.S.	-	↓	-	-	B	↑	-	-
Volatile residue	-	↓	-	↑	-	-	-	↑
NO_2	-	-	-	-	-	-	-	-
NO_3	-	-	-	-	-	-	-	↑
NH_3	-	↑	-	-	-	↓	-	-
TKN	-	↑	-	↓	-	-	-	-
OPO_4	-	-	-	-	-	-	-	-
TP	-	-	-	-	-	-	-	-
Chlorophyll _a_	-	↓	-	↓	B	↑	-	↑
Chlorophyll _b_	-	-	-	-	-	↓	-	-
Chlorophyll _c_	-	↓	-	-	-	↓	-	↑
Phaeophytin	B	↑	-	-	-	↓	-	-

TABLE I (continued)

Parameter	February Depth	February Season	April Depth	April Season	July Depth	July Season	December Depth	December Season
	1983							
Multivariate model	-	*	*	*	*	*	*	*
Temperature	-	↓	S	↑	S	↑	B	↓
Salinity	-	-	B	↓	B	-	B	↑
pH	-	-	-	-	S	-	-	-
D.O.	-	↑	-	↓	-	↓	S	↑
C.O.D.	-	↓	-	-	-	-	-	↑
Turbidity	-	-	-	-	-	↓	-	↑
S.S.	-	↓	B	-	-	↓	-	-
Volatile residue	-	-	B	-	-	↑	-	-
NO_2	-	-	B	↑	-	↓	-	↑
NO_3	-	↓	-	↑	-	↓	S	↑
NH_3	-	↑	-	-	-	↓	-	↑
TKN	-	-	-	-	-	-	-	↑
OPO_4	-	↑	B	-	-	↓	-	↑
TP	-	↑	-	↑	-	↓	-	↑
Chlorophyll a	-	↓	S	↓	B	↓	-	↑
Chlorophyll b	-	-	-	↑	-	-	S	↑
Chlorophyll c	-	↓	-	-	B	-	-	↑
Phaeophytin	-	-	-	-	B	↑	-	↓

lowest during the spring and summer months, corresponding to periods of greatest stratification (Figure 2b, Table I). Surface salinities were depressed (as low as 25 ppt) due to an extention of the Chesapeake Bay influence offshore. The effects of the 1980-81 drought were evidenced at the NDS, with salinities higher during the first year in comparison to the remainder of the study. The basic buffering capacity of the marine system held pH readings near 8, except for during the Winter of 1982 when values were somewhat higher (Fig. 2c, Table I). Dissolved oxygen levels were generally inversely related to water temperature (Fig. 2d, Table I). The vertical patterns of oxygen content indicated that oxygen depletion of bottom waters was not a problem. In fact, oxygen readings were often near saturation levels and bottom oxygen measurements were only slightly below surface values during two of the summer cruises.

The indices of materials suspended in the water column generally exhibited low values, but showed seasonal trends (Figure 3, Table I). Lowest values of suspended solids, VNR and C.O.D. were generally found during the spring and summer with highest values occurring during the Fall. The major exception to this pattern occured in July of 1983 when higher VNR values were observed at NDS, possibly associated with levels of dead plant material in the water (as evidenced by the phaeophytin; Figure 5d). The turbidity of waters was uniformly low, although some of the same seasonal patterns were apparent (Figure 3d). Highest turbidity readings were found for the bottom waters during periods of high chlorophyll _a_ content (Figure 5a).

The nutrients in the waters of the study area were quite low, often at levels below detection limits (Figure 4). Seldom were there indications of significant vertical stratification (Table I). Orthorphosphates were below

Figure 2. Physical parameters monitored at the proposed Norfolk Disposal Site (NDS) for 1981-1983. Solid lines and asterisks represent surface values, and broken lines and squares are bottom measurements. The symbols represent mean values (n=18), with ± standard error bars indicated. When standard error bars were smaller than the symbols, they were omitted for presentation purposes: a) temperature (^{o}C), b) salinity ($^{o}/oo$), c) pH, d) dissolved oxygen (DO) (mg/1).

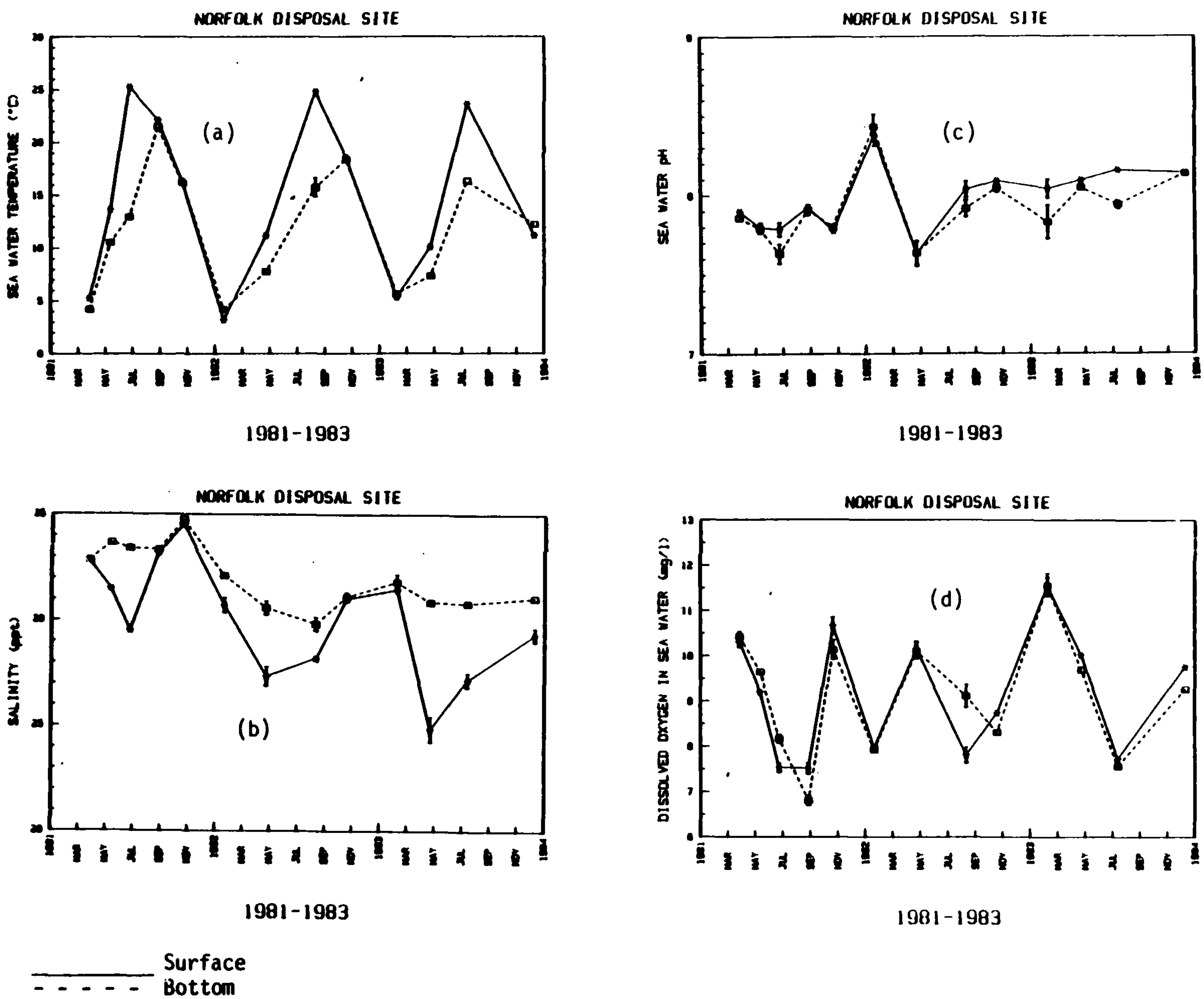
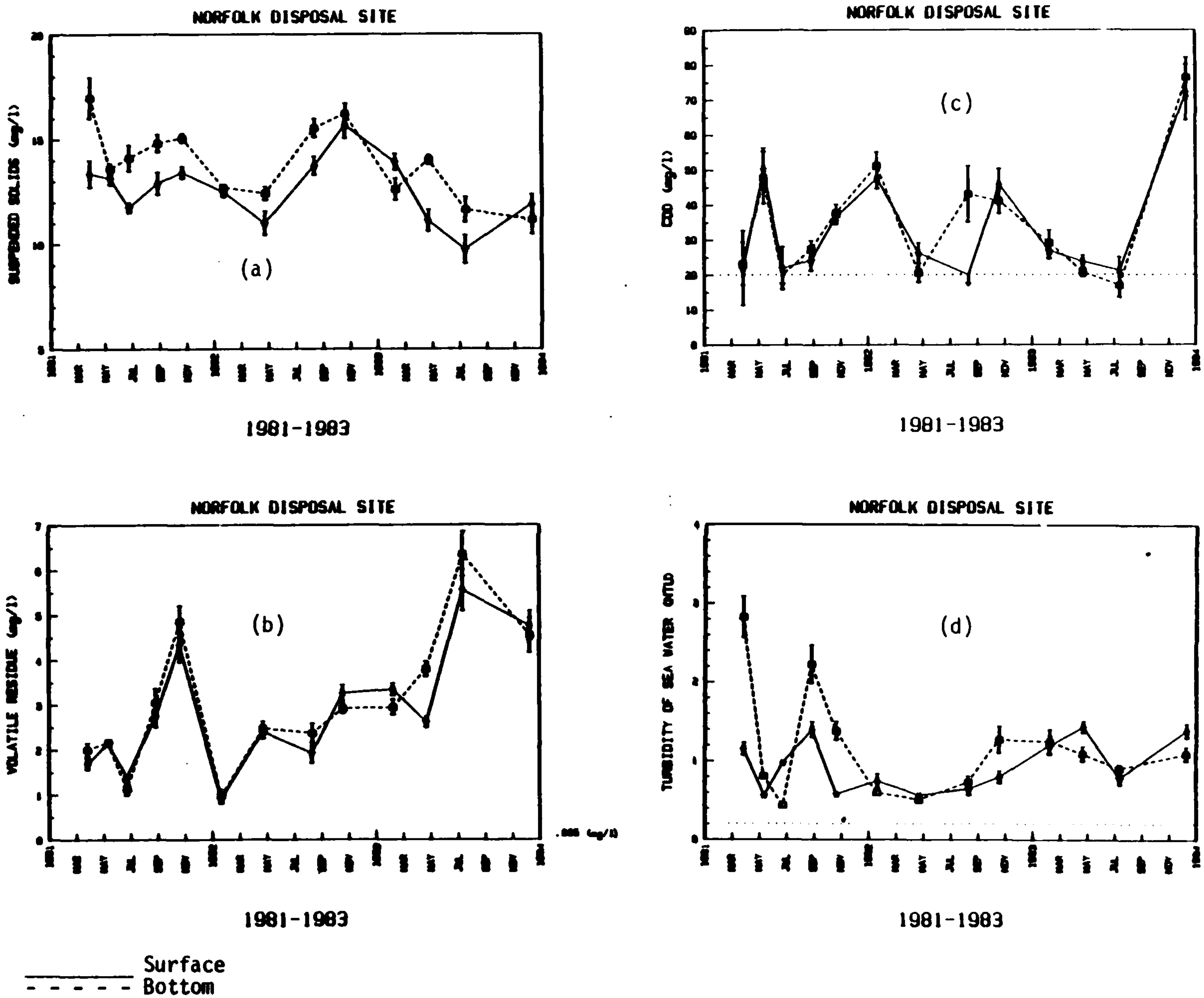

NORFOLK DISPOSAL SITE
(a)
SEA WATER TEMPERATURE (°C)
1981-1983
NORFOLK DISPOSAL SITE
(c)
SEA WATER pH
1981-1983
NORFOLK DISPOSAL SITE
(b)
SALINITY (ppt)
1981-1983
NORFOLK DISPOSAL SITE
(d)
DISSOLVED OXYGEN IN SEA WATER (mg/l)
1981-1983
Surface
Bottom

Figure 3. Physical and chemical parameters monitored at the proposed Norfolk Disposal Site (NDS) for 1981-1983: a) suspended solids (mg/1), b) volatile residue (mg/1), c) chemical oxygen demand (COD) (mg/1), d) turbidity of sea waters (NTU).



NORFOLK DISPOSAL SITE
SUSPENDED SOLIDS (mg/l)
(a)
1981-1983
NORFOLK DISPOSAL SITE
COD (mg/l)
(c)
1981-1983
NORFOLK DISPOSAL SITE
VOLATILE RESIDUE (mg/l)
(b)
1981-1983
NORFOLK DISPOSAL SITE
TURBIDITY OF SEA WATER (NTU)
(d)
1981-1983
Surface
Bottom

detection limits during 1981 and 1982 and present in concentrations approaching the limits in 1983 (Figure 4a). Total phosphorous was higher during the spring and fall, and low during the summer, although it remained below detection limits during all of the 1982 cruises (Figure 4b, Table I). Likewise, nitrites and nitrates were below detection limits for most of the study, with detectable but low levels reported during the fall of 1982 and the spring and fall of 1983 (Figure 4c, d). Ammonia levels were quite low throughout the study, but a distinct seasonality was apparent: highest levels were found during the Winter and lowest levels measured during the summer (Figure 4c, Table I). The TKN values followed a similar, but considerably more depressed pattern with highest values observed during December of 1983 (Figure 4f). The higher levels of TKN observed were believed to be associated with a phytoplankton bloom at the NDS (as evidenced by the highest readings recorded for chlorophylls _a_ and _c_, as well as, total phosphorus and C.O.D.; Figures 5a, c, 3c and 4b, respectively).

Chlorophyll content of the waters of NDS were moderately low, but followed an expected seasonal pattern (Figure 5). Chlorophylls _a_ and _c_ were highest in the Fall and lowest in the late Spring - Summer months (Figure 5a, c). The times of lowest chlorophyll values corresponded to the periods of greatest stratification and lowest nutrient levels. Chlorophyll _b_ was detected in higher levels in 1981 than in 1982 or 1983, but no obvious seasonal patterns were observed and the levels never approached those observed for chlorophylls _a_ or _c_ (Figure 5b). Bottom water samples tended to have greater chlorophyll levels than surface samples, except during the period of Spring stratification (Figures 5a-c). However, during the maximum stratification bottom values were higher. Phaeophytin values were always higher in the bottom waters with peak periods of phaeophytin concentration

Figure 4. Nutrient parameters monitored at the proposed Norfolk Disposal Site (NDS) for 1981-1983: a) Orthophosphates (mg/l x 10^{-3}), b) phosphorus (mg/l x 10^{-2}), c) Nitrite (μg/l), d) Nitrate (mg/l x 10^{-2}).

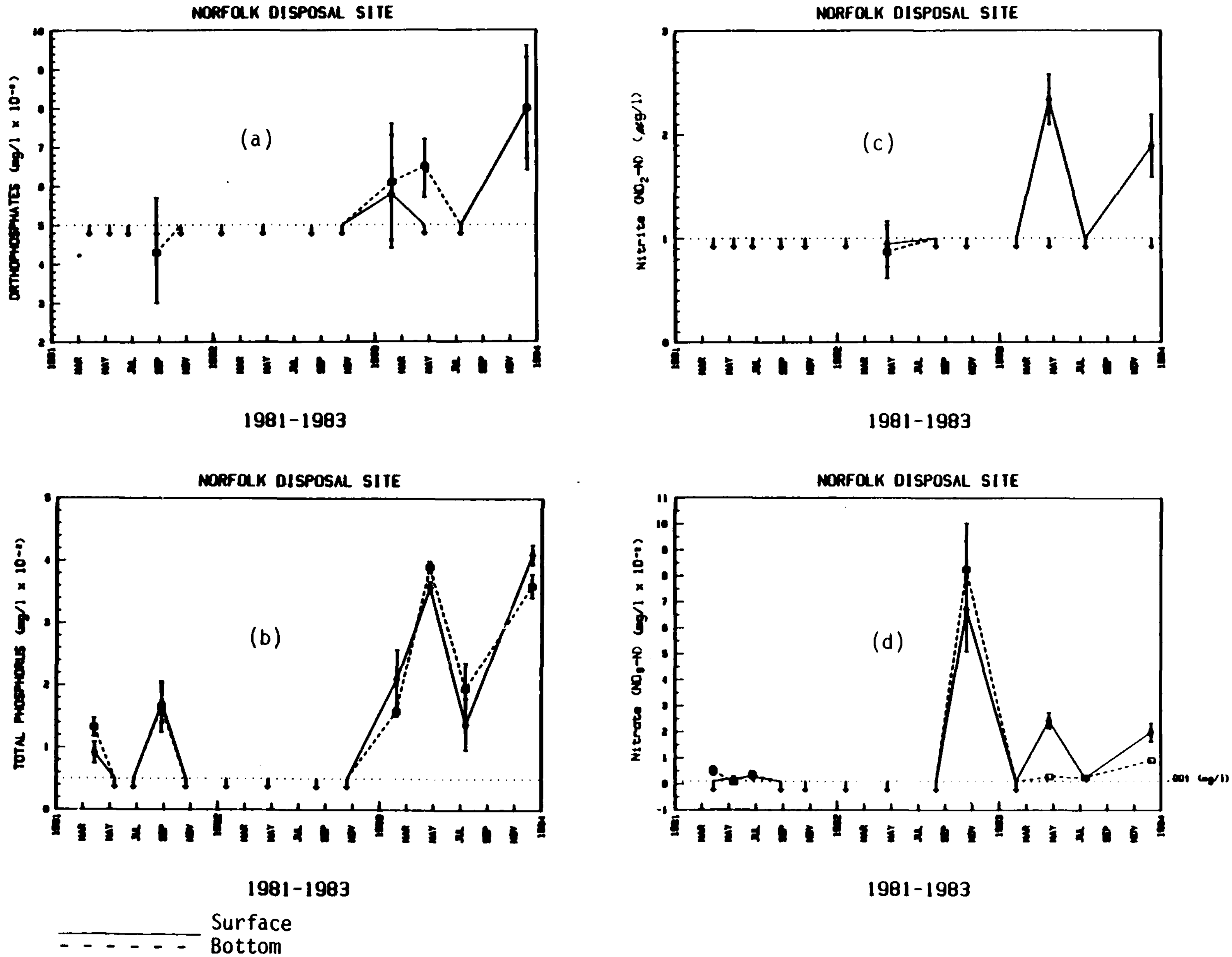

NORFOLK DISPOSAL SITE
(a)
ORTHOPHOSPHATES (mg/l × 10⁻²)
1981-1983
NORFOLK DISPOSAL SITE
(c)
1981-1983
NORFOLK DISPOSAL SITE
(b)
TOTAL PHOSPHORUS (mg/l × 10⁻²)
1981-1983
NORFOLK DISPOSAL SITE
(d)
.001 (mg/l)
1981-1983
Surface
Bottom

Figure 4 (continued). e) Ammonia (mg/l x 10^{-2}), f) Kjeldhal Nitrogen (mg/l x 10^{-1}).

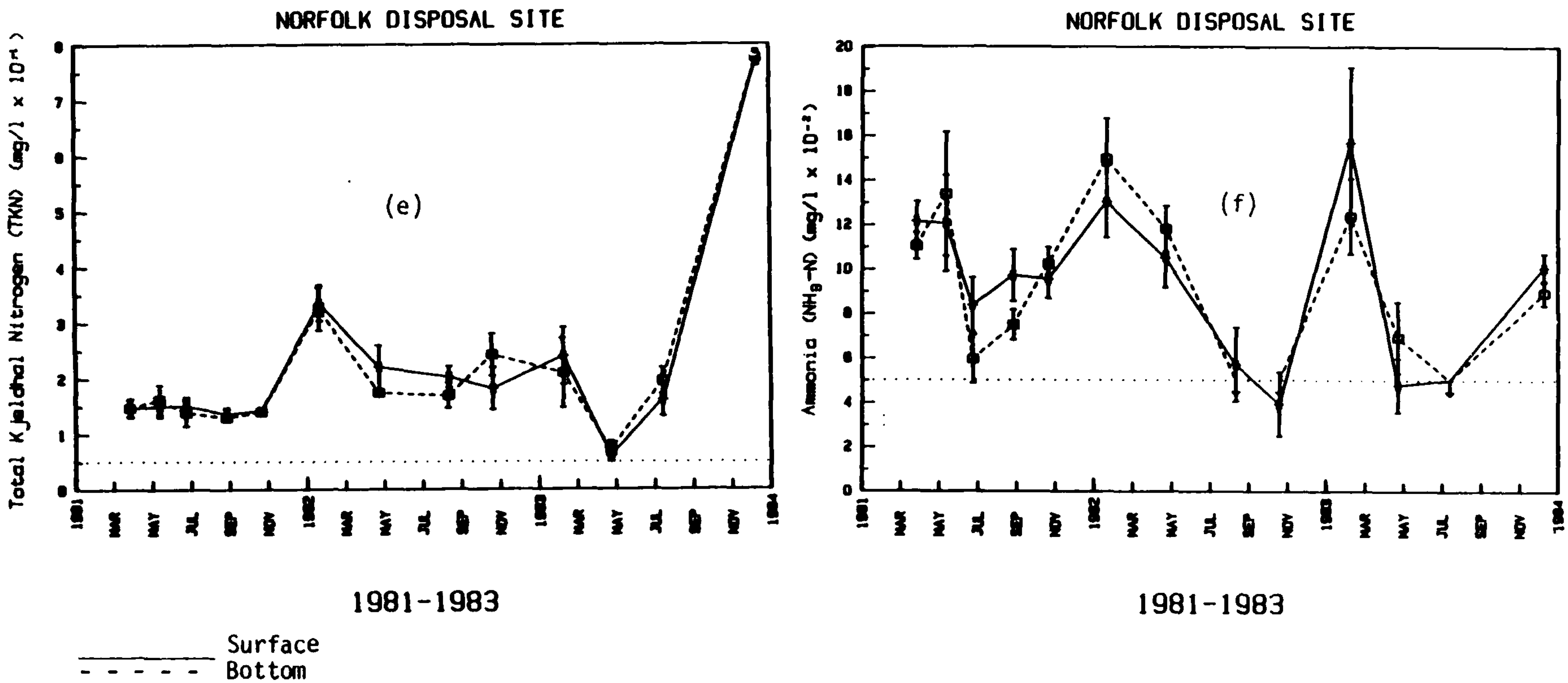
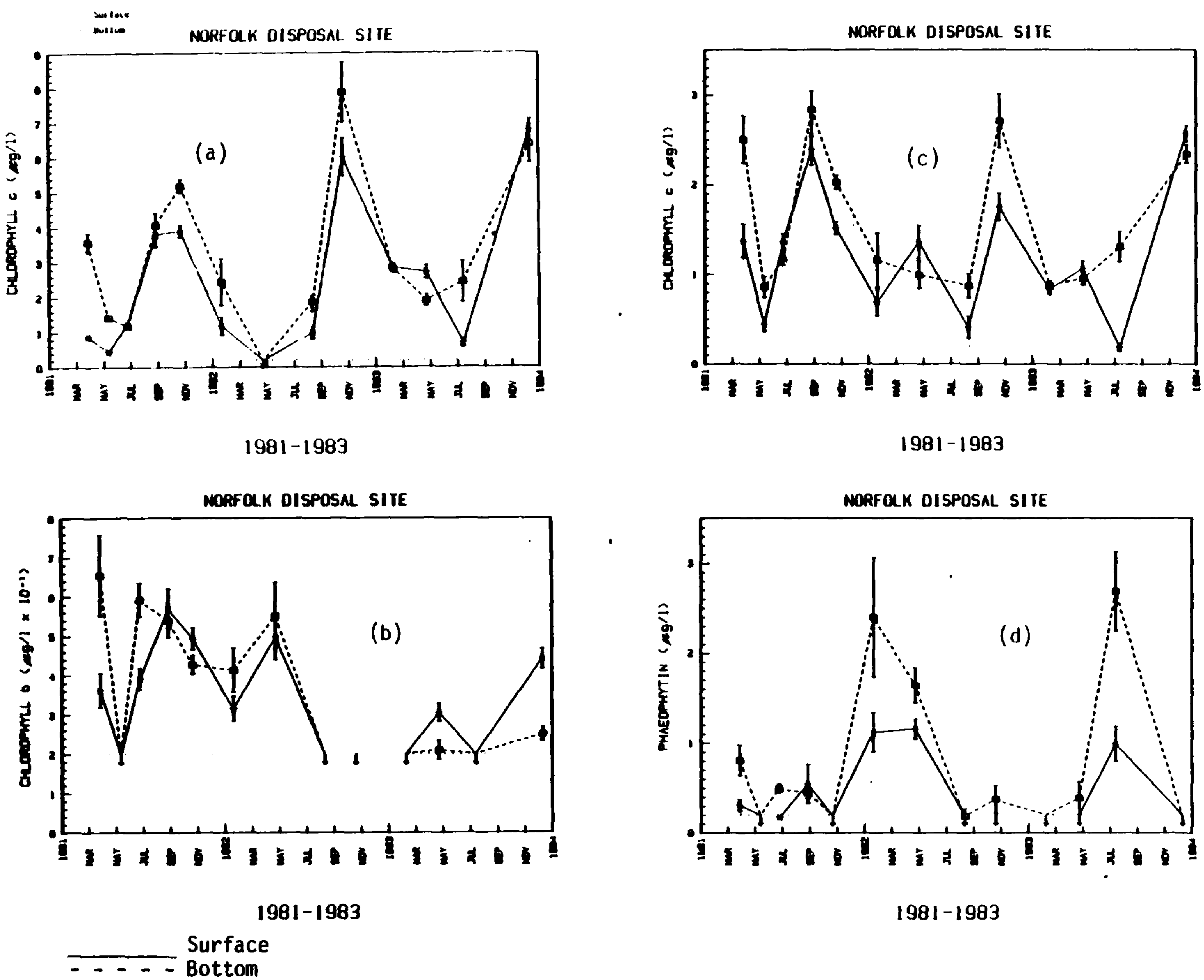

NORFOLK DISPOSAL SITE
(e)
Total Kjeldhal Nitrogen (TKN) (mg/l x 10⁻¹)
1981-1983
NORFOLK DISPOSAL SITE
(f)
Ammonia (NH3-N) (mg/l x 10⁻²)
1981-1983
Surface
Bottom

Figure 5. Chlorophyll and phaeophytin monitored at the proposed Norfolk Disposal Site (NDS) for 1981-1983: a) chlorophyll a ($\mu g/l$). b) chlorophyll b ($\mu g/l \times 10^{-1}$), c) chlorophyll c ($\mu g/l$), d) Phaeophytin ($\mu g/l$).

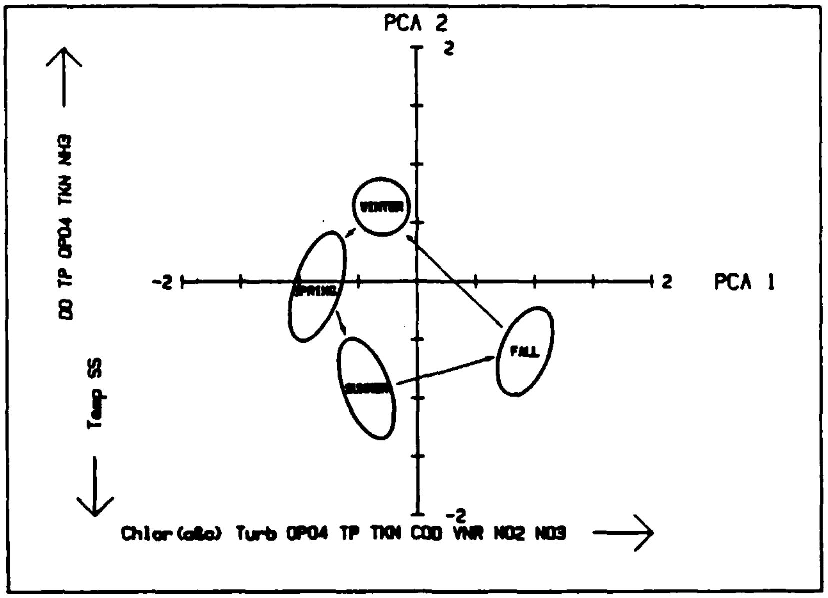

NORFOLK DISPOSAL SITE
(a)
CHLOROPHYLL c (µg/l)
1981-1983
NORFOLK DISPOSAL SITE
(c)
CHLOROPHYLL c (µg/l)
1981-1983
NORFOLK DISPOSAL SITE
(b)
CHLOROPHYLL b (µg/l x 10⁻¹)
1981-1983
NORFOLK DISPOSAL SITE
(d)
PHAEOPHYTIN (µg/l)
1981-1983
Surface
Bottom

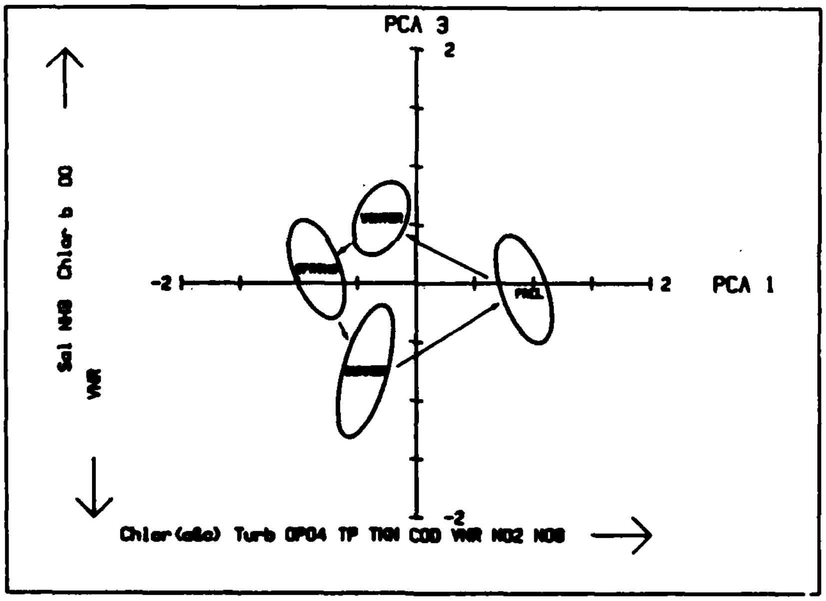
occurred in early 1982 and mid-1983. (Figure 5d)

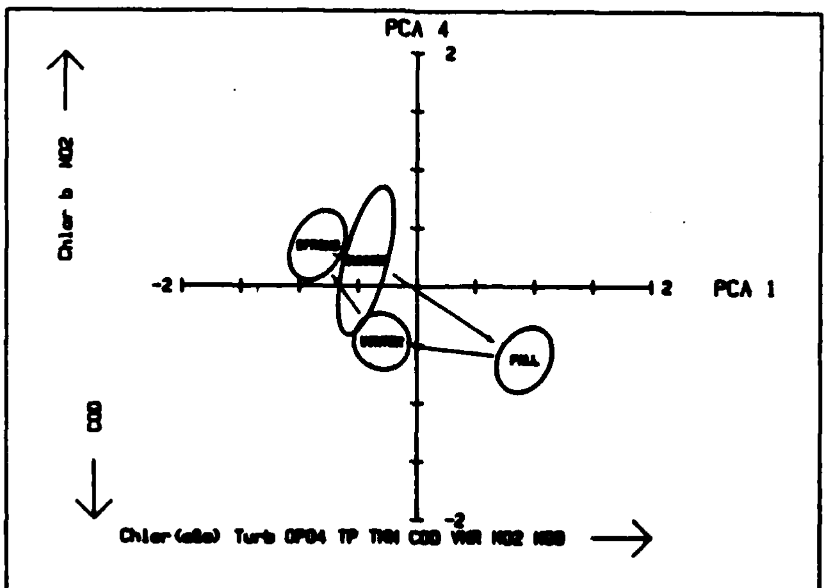
In order to summarize the water quality patterns observed at NDS, a PCA was run on the entire data set. The first four PCA factors accounted for over 50% of the variance in the data (20%, 13%, 11%, and 9%, respectively, for factors 1-4). The 95% confidence ellipses of the combined seasonal data sets were plotted on graphs of the principal axes: PCA 1 vs. PCA 2; PCA 1 vs. PCA 2; PCA 1 vs PCS 3; and PCA 1 vs. PCA 4 (Figure 6). The PCA 1 represented the changes in chlorophylls, organics, and nutrients that generally occur in the water quality cycle: from a low in the Spring to a high in the Fall and back again. The seasonal factor (PCA 2) represented the increase in temperature and suspended solids, and the associated decrease in dissolved oxygen and certain nutrients which occur between the cold and warm months (Figure 6a). The PCA 3 was positively related to salinity, ammonia, chlorophyll b, and D.O. which increased during the Winter; and negatively related to volatile residue which increased in the Summer (Figure 6b). Primarily, the PCA 4 was inversely related to C.O.D. which was elevated in the Fall and Winter; and to a lesser extent, PCA 4 was directly related to chlorophyll b and to nitrites for the few periods when they were detectable (Figure 6c). Thus, the patterns presented on Figure 6 summarize most of the major annual cycles in water quality at the NDS, which have been detailed in Figures 2-5.

In order to more thoroughly explore the spatial patterns of water quality and to test trend assessment statistical models under baseline conditions, a series of MANOVAs were conducted on data from each pair of consecutive cruises to test season-area interaction effects (i.e., water quality changes occurring within the NDS not explained by seasonal patterns and not observed elsewhere; see Alden, 1984 for a more detailed discussion of trend

Figure 6. Scores for the first four factors of Principal Component Analysis summarizing the water quality patterns observed at the proposed Norfolk Disposal Site (NDS) for 1981-1983.


PCA 2
2
-2
2
-2
PCA 1
DO TP OPO4 TKN NH3
Temp SS
FALL
Chlor(a&c) Turb OPO4 TP TKN COD VNR NO2 NO3


PCA 3
2
-2
2
-2
PCA 1
Sal NH3 Chlor b DO
VNR
Chlor(a&c) Turb OPO4 TP TKN COD VNR NO2 NO3


PCA 4
2
-2
2
-2
PCA 1
Chlor b NO2
COD
FALL
Chlor(a&c) Turb OPO4 TP TKN COD VNR NO2 NO3

assessment statistics). As might be expected for baseline conditions, most of the tests indicated no significant differences (α = 0.001) between the water quality of stations within NDS in comparison with that observed for stations outside the Site. However, three of the 12 tests (June - August 1981, August - October 1982, and October - February 1982-83) indicated that there were significant season-area effects.

A series of univariate analyses were performed on the data from the cruises in order to determine the parameters responsible for the significance in the multivariate models, and to define the nature of the spatial patterns. The a priori hypothesis was that the plume from the Chesapeake Bay crosses NDS from time to time, and creates spatial differences in water quality between the stations. Normally, the Bay plume moves in a pattern which is southwest of the site, but it has been observed occasionally to cut across this region (Campbell and Thomas, 1981). Therefore, a series of ANOVAs were conducted to test whether the various water quality parameters for stations located in the southwest portion of the study area (1, 3, 5, 6, 8) were significantly different from those observed for stations to the north and east (11, 13, 14, 16) (Figure 1). A more definitive test of spatial patterns involved the use of the Duncan's Multiple Range test as a method to classify groups of stations which were statistically similar with respect to each of the various water quality parameters. The univariate tests were run on logarithmically transformed data and Duncan's test was not performed unless an ANOVA indicated significant differences (α = 0.001) between stations for the parameter.

In June of 1981, the stations from the southwestern portion of the study area had significantly higher levels of ammonia and TKN from stations to the north and east (Table II). The analysis of August 1981 data yielded

TABLE II

Results of analysis of Chesapeake Bay plume effects. Mean values (standard errors in parentheses) for each group are indicated. Only the results of ANOVA's indicating significant results (α=0.001) are presented. Duncan's Multiple Range tests (α=0.05) were employed as a classification tool to indicate patterns between stations. The letters indicate statistically homogeneous subgroups of stations (a=highest values, etc.).

Cruise	Parameter	S.W.	N.E.
June 1981	TKN	0.20 (0.012)	0.07 (0.012)
	NH_3	0.10 (0.006)	0.03 (0.010)

Duncan's Test of Stations

	S.W.					N.E.			
	1	3	5	8	6	11	13	16	14
TKN	0.20ab	0.20ab	0.14bc	0.27a	0.20ab	0.06d	0.12cd	0.05d	0.05d
NH_3	0.10ab	0.09ab	0.08bc	0.10ab	0.13a	0.04c	0.09bc	0.00d	0.00d

Cruise	Parameter	S.W.	N.E.
August 1981	TP	0.02 (0.003)	0.007 (0.002)
	Chlorophyll _b_	0.62 (0.027)	0.45 (0.026)
	Chlorophyll _c_	2.86 (0.048)	2.13 (0.048)

Duncan's Test of Stations

	S.W.					N.E.			
	1	3	5	8	6	11	13	16	14
TP	0.04a	0.015cd	0.029b	0.012cde	0.021bc	0.003dc	0.001e	0.009cde	0.013cd
Chlorophyll _a_	5.74a	4.29abc	3.50bcde	3.77abcd	2.74cde	2.57de	2.18e	4.84ab	5.00ab
Chlorophyll _b_	0.55bc	0.80a	0.77ab	0.51c	0.50c	0.28d	0.47c	0.56bc	0.49c
Chlorophyll _c_	2.92ab	3.58a	2.93ab	2.77ab	2.22bcd	1.67cd	1.62d	2.86ab	2.54abc

TABLE II (continued)

Cruise	Parameter	S.W.	N.E.
October 1982	Temperature	18.37 (0.002)	18.64 (0.003)
	NH_3	0.06 (0.012)	0.01 (0.006)

	Duncan's Test of Stations								
	S.W.					N.E.			
	1	3	5	8	6	11	13	16	14
Temperature	18.22c	18.32bc	18.49bc	18.45bc	18.35bc	18.60b	19.00a	18.59b	18.44bc
Turbidity	1.42a	1.74a	0.76b	.75b	.76b	.58b	.67b	.69b	1.66a
NH_3	0.07ab	0.08ab	0.0c	0.05bc	0.11a	0.0c	0.0c	0.0c	0.03c

Cruise	Parameter	S.W.	N.E.
February 1982	Temperature	4.89 (0.004)	4.89 (0.034)
	Salinity	30.32 (0.001)	31.99 (0.005)
	Dissolved Oxygen	11.15 (0.021)	12.02 (0.004)
	OPO_4	0.011 (0.001)	0.000

	Duncan's Test of Stations								
	S.W.					N.E.			
	1	3	5	8	6	11	13	16	14
Temperature	4.80c	4.78c	4.98c	4.94c	4.96c	5.79b	5.76b	5.97a	5.90b
Salinity	30.34b	30.21b	30.30b	30.40b	30.33b	32.14a	33.09a	31.37a	31.37a
Dissolved Oxygen	9.21d	11.30c	11.59bc	11.85b	11.90ab	11.95a	11.90ab	12.30a	11.95a
Turbidity	2.44a	1.57b	1.12c	1.62b	0.96cd	0.87de	0.58f	1.04ed	0.78e
OPO_4	0.013b	0.013b	0.015a	0.006d	0.007c	0.000e	0.000e	0.000e	0.000e
Chlorophyll *a*	3.68a	2.90bc	2.54c	2.52c	2.69c	2.57c	2.11d	3.34ab	3.18ab

similar results, except the parameters exhibiting significant elevations at the southwestern stations were the chlorophylls and total phosphorous (Table II). During October of 1982, the colder more turbid and slightly ammonia-enriched waters of the Bay appeared to affect the stations in the southwestern portion of the study area, particularly in contrast to the eastern stations which were influenced by more oceanic conditions. The February 1982 cruise data provided the most extensive evidence of the influence of Chesapeake Bay water on the spatial patterns of the water quality of the study area. Temperature, salinity, dissolved oxygen, orthophosphates, turbidity and chlorophyll _a_ all exhibited patterns which might be expected for a period of plume effects: the waters of the southwestern stations had lower temperatures, lower salinities and dissolved oxygen content, and higher turbidities, phosphates and chlorophyll _a_, while the stations in the northeastern portion of the study area were more oceanic in nature (i.e., more moderate temperatures, higher salinities, low turbidities, low nutrients, and low chlorophyll).

Comparisons to Previous Studies

The water quality of the study area appears to be quite good and generally follows patterns observed by previous investigators. Kester and Courant (1973) and Kuo et al. (1975) review and summarize most of the water quality studies conducted in the Chesapeake Bay and nearshore coastal waters. It is clear that the water quality data from the present study falls well within the range of values presented in these reviews. In fact, the data reflect the more neritic location of the study area when compared to those reported for investigations in estuarine regions of the Chesapeake Bay: nutrients, chlorophyll levels, organic content (VNR), suspended solids

and turbidity readings were lower; salinities and oxygen levels were higher; and temperature and pH were more stable. As might be expected, water quality of the coastal waters of the Norfolk Disposal Site was much better than that found for local estuaries more directly impacted by man (VSWCB, 1976). Likewise, the water quality conditions in the vicinity of NDS appeared to be much better than the coastal regions of the New York Bight, with no indications of the hypoxia or intense eutrophication observed in those waters (Pearce, 1981).

Several trends were apparent in comparing the data from the present study to that reported by the Superflux investigators during 1980 (Campbell and Thomas, 1981). The Superflux program was conducted during a record drought, while the present study covered a period of much more normal rainfall for the area. It was not too surprising, therefore, that water quality changes associated with increased runoff from the Chesapeake Bay were observed.

Salinities were generally lower than those reported for the area by Wong and Todd (1981). Nutrients, particularly ammonia, were observed in higher concentrations than those reported by Wong and Todd (1981). These investigators reported that N/P ratios were often less than 15, indicating nitrogen limitation in waters near the mouth of the Chesapeake Bay. During the present study, a higher level of runoff from the Bay apparently supplied higher levels of ammonia to the study area, so that phosphorous may be considered to be more limiting (i.e., N/P ratios greater than 15). Of course, the concept of single limiting factors, particularly in dynamic coastal waters, is of questionable ecological utility. Primary production appears to be limited by a general paucity of nutrients when the study area is compared to the waters of the Chesapeake Bay.

Suspended solids, volatile residue and chlorophyll concentrations were generally higher during the present study than during Superflux investigations (Gingerich and Oertel, 1981; Robertson and Thomas, 1981; and Kator and Zulkoff, 1981). These trends also reflect the higher level of Bay runoff during the period of the study. Although still relatively low, primary production (as indicated by chlorophyll content) was presumably higher due to the increase in nutrients from runoff. The higher levels of production may, in turn, account for the higher concentrations of particulate organic matter.

The horizontal water quality patterns observed during the three periods of spatial heterogeneity (June - August 1981; August - October 1982; October - February 1982-83) appeared to echo patterns observed during the Superflux study during June 1980 (Kendall, 1981). The salinity distribution determined by remote sensing techniques employed during Superflux indicated that the Chesapeake Bay plume occasionally flowed out onto the shelf and cut across the area of the NDS. The occasional periods of spatial heterogeneity in water quality between the southwestern stations and the northeastern stations under more oceanic influences complicate statistical models to a degree. However, the fact that these events have been documented and defined under baseline conditions allows them to be taken into account in future trend assessment studies. The Bay plume effects can be evaluated statistically as an alternate hypothesis to dredged material disposal effects, so that this potentially confounding natural pattern can be eliminated before the man-made impacts are evaluated.

Minimum Detectable Impacts in Water Quality

In order to define the levels of change which might represent "statistically significant" effects under the context of natural spatio-temporal

variability, minimum detectable impacts (MDIs) were calculated for each variable in the seasonal data sets (Table III). The MDIs ranged from less than a 5% change for parameters exhibiting low variability to over 500% for the most variable parameters. However, the parameters with the largest MDIs were generally those with concentrations very near to the detection levels. Therefore, the absolute values of the parameters resulting from the hypothetical "impacts" were never extreme in an ecological sense. Even the "impacted" values calculated for single samples were quite moderate, despite the fact that the level of change must be greater for statistical detection in only one post-impact sample.

It might be noted that the direction of change for the calculation of MDIs for the chlorophylls was chosen to be negative to represent inhibition or toxicity to the phytoplankton population. The rationale behind this choice was that the chlorophyll levels at NDS were quite low throughout the year, so that the greatest impact which could be reasonably expected would be decreased activity by the primary producers. Unlike the more estuarine waters of the Chesapeake Bay, the chlorophyll content (i.e., plant biomass) of waters at the site would have to rise orders of magnitude to even approach levels which might be considered eutrophic. The MDIs calculated for chlorophyll increase represented, at most, a change of 2-3x (200-300%). Thus, although the chlorophyl enhancement MDIs are not shown in Table III, they do represent a reasonable level for statistical detection.

The MDIs for the NDS water quality indicated that most changes would be statistically detected before the absolute levels of the various parameters would become extreme in an ecological sense. Few of the projected values for "impacted" parameters fell outside of the natural range reported by

TABLE III

The estimated MDIs for water quality parameters at the Norfolk Disposal Site. The MDI values represent the percent change (+ for parameters expected to be enhanced; - for parameters expected to be decreased) estimated to be necessary to produce a statistically significant difference (α=0.001) from seasonal mean values of the parameters. The values in parentheses represent the absolute "impacted" values resulting from such a change (units are the same as in Figs. 2-4).

	MDIs							
	Season-Area Interaction Model				Single Sample Model			
Parameter	Spring MDI (x)	Summer MDI (x)	Fall MDI (x)	Winter MDI (x)	Spring MDI (x)	Summer MDI (x)	Fall MDI (x)	Winter MDI (x)
D.O.	- 5(9.49)	- 5(7.53)	- 5(8.77)	- 5(8.25)	- 30(6.86)	- 65(3.11)	- 35(6.16)	- 45(5.45)
pH	- 5(7.46)	- 5(7.64)	- 5(7.57)	- 5(7.75)	- 15(6.66)	- 15(6.72)	- 10(7.20)	- 25(6.07)
C.O.D.	+140(91.02)	+310(88.61)	+130(129.09)	+130(84.66)	+350(142.20)	+540(140.46)	+220(165.14)	+320(145.85)
Turbidity	+130(1.75)	+180(3.21)	+ 60(1.51)	+ 80(2.04)	+150(2.07)	+300(4.05)	+220(3.47)	+230(3.99)
NO_2	+360(1.40)	BDL	+330(1.32)	BDL	+620(5.43)	BDL	+660(4.03)	BDL
NO_3	+240(0.021)	BDL	+140(0.085)	BDL	+780(0.044)	BDL	+740(0.251)	BDL
OPO_4	+550(0.005)	+160(0.003)	+280(0.012)	+240(0.016)	+910(0.013)	+1390(0.014)	+610(0.021)	+930(0.023)
TP	+210(0.039)	+180(0.039)	+280(0.049)	+260(0.039)	+310(0.051)	+760(0.072)	+290(0.051)	+550(0.063)
TKN	+100(0.241)	+160(0.458)	+250(1.156)	+350(0.669)	+260(0.503)	+290(0.625)	+190(1.09)	+350(1.10)
NH_3	+ 70(0.184)	+350(0.202)	+190(0.224)	+100(0.366)	+310(0.406)	+570(0.324)	+290(0.301)	+310(0.550)
S.S.	+ 5(12.75)	+ 80(25.51)	+ 55(21.60)	+ 45(18.31)	+ 65(20.71)	+125(29.32)	+ 75(24.34)	+ 75(23.62)
VNR	+ 75(4.74)	+185(9.78)	+ 95(8.91)	+160(5.16)	+115(5.59)	+320(12.89)	+185(11.72)	+160(5.19)
Chlorophyll a	-170(<0)	-170(<0)	- 10(5.55)	-110(<0)	- 50(0.56)	-160(<0)	- 80(1.21)	- 40(1.38)
Chlorophyll b	- 90(0.04)	-140(<0)	-120(<0)	- 60(0.09)	-290(<0)	-220(<0)	-220(<0)	-280(<0)
Chlorophyll c	- 60(0.33)	-130(<0)	- 10(1.72)	-140(<0)	-220(<0)	-130(<0)	-100(<0)	-220(<0)
Phaeophytin	+390(1.50)	+310(3.97)	+490(1.11)	+470(4.52)	+150(1.39)	+440(3.81)	+873(1.79)	+140(1.97)

Note: BDL = At least one cell in the model contains all values which are below detection limits.

Kester and Courant (1973) for none of the estuarine of the lower Chesapeake Bay and none even approached the water quality criteria or reference levels recommended by State and Federal agencies for the protection of marine life and the prevention of eutrophication (VSWCB, 1976; EPA, 1973). Of course, even the MDIs were somewhat conservative since empirical tests with data sets with computer simulated impacts have indicated that statistical detection with multivariate models is often possible for changes of only 30% of the estimated MDI level whenever more than one parameter is being impacted at the same time (Alden, 1984).

Thus, it is anticipated that any water quality impacts associated with disposal activities will be statistically detected during trend assessment studies at a level below that which may be of acute ecological significance. This is the desired situation, if the monitoring regime and the associated statistical models are to act as an "early warning system" for the detection of an impact before the environment deteriorates excessively (Alden, 1984).

Annual Variability and Statistical Detection

As has been discussed in a previous report (Alden, 1984), year to year variation in environmental data tends to confound the statistical detection of impacts during trend assessment studies. The MDIs estimated for baseline data, and the associated variability, are accumulated. However, as the data base grows, the MDIs would be expected to increase asymptotically, since all but the most aperiodic baseline "noise" has been taken into account.

In order to determine whether this theoretical situation occurs with the NDS water quality statistical models, a series of MDIs were estimated for a data base which expanded from one to four cruises worth of seasonal data. The MDIs were first calculated for the August 1981 data, then calcu-

lated for June and August 1981 data sets combined. The data from the Summer cruise of 1982 was included and the MDIs recalculated, and finally, the 1983 Summer data was incorporated in the data base for the calculations.

The results of the MDI calculations for the Summer cruise series are presented in Table IV. Although all of the MDIs increase as the data set became more inclusive, the MDIs for some of the parameters appear to have approached an asymptote: primarily D.O., pH, C.O.D., turbidity. On the other hand, the MDIs for the nutrients appeared to still be increasing with the most inclusive data set, and the value for chlorophyll _a_ changed unexpectedly (especially for the single sample model) when the 1983 data were included. When the series is expanded to include the data now being collected for the Summer of 1984, perhaps more of the parameters will have reached an asymptotic MDI level.

The trend for the absolute values of MDIs to increase as the baseline data set is expanded may be disconcerting at first consideration. One may be led to believe that it is better to monitor baseline conditions for a relatively short period, so that the MDI levels are small and detection potential is high. However, this scenario would lead to numerous "false alarms" where natural, albeit somewhat aperiodic, changes are interpreted as impacts. Since these "false alarms" may prove to be costly in terms of additional studies being generated and/or a moratorium on the suspected activity, it would be more reasonable to assemble a more representative long term baseline data set. Such a data set should theoretically take into account most of the natural variability of conditions at the disposal site, so that only "true" impacts are detected. The level of monitoring effort which produces asymptotic MDIs would be expected to account for nearly all natural patterns, except those caused by extreme aperiodic occurrences

TABLE IV

The estimated MDIs for water quality parameters for Summer data sets. The MDI values were calculated successively for cumulative seasonal data collected from 1981 - 1983.

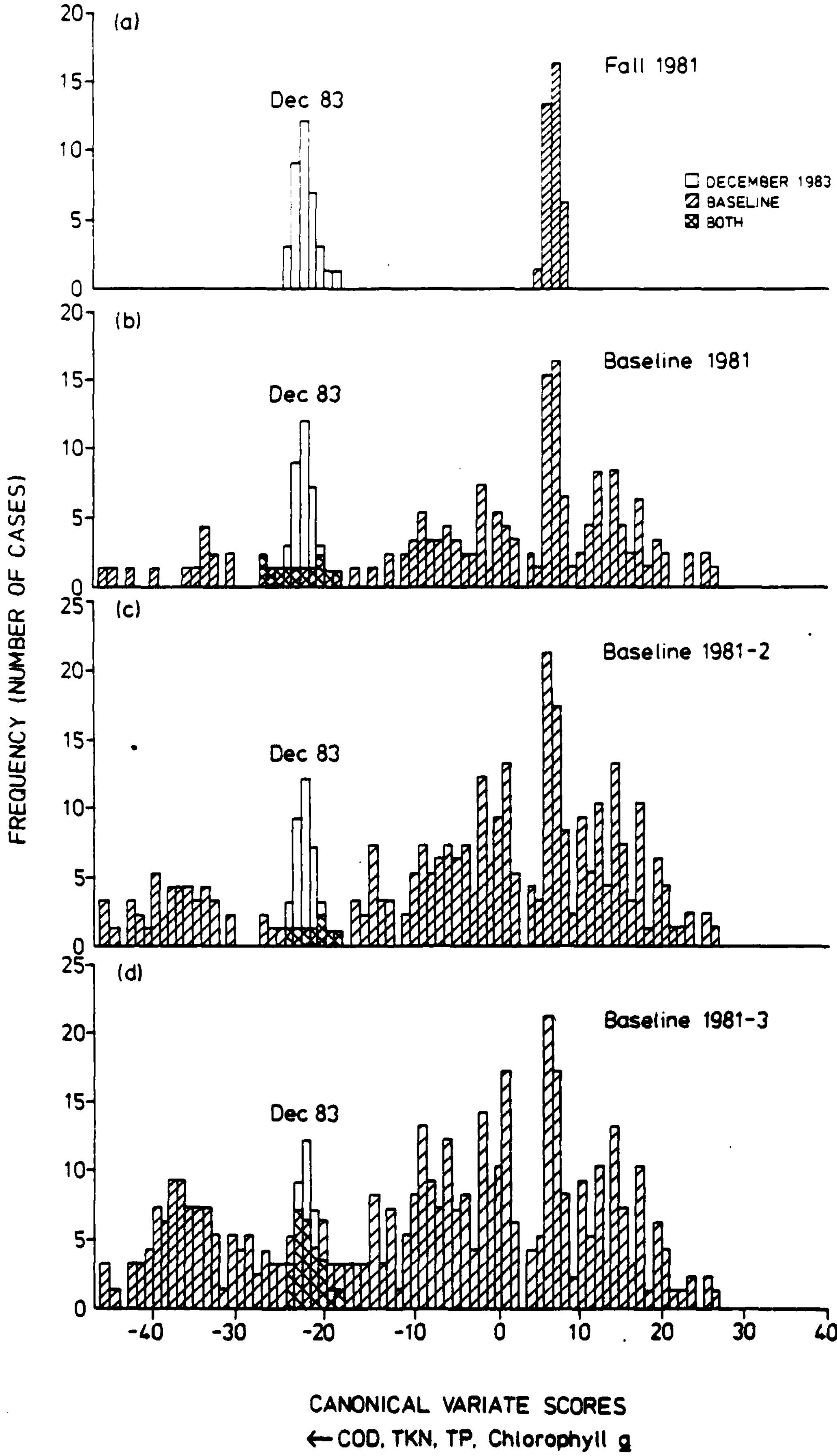
	MDIs							
	Season-Area Interaction Model				Single Sample Model			
Parameter	August 1981	Summer 1981	Summer 1981-82	Summer 1981-83	August 1981	Summer 1981	Summer 1981-82	Summer 1981-83
D.O.	- 5	- 5	- 5	- 5	- 25	- 40	- 65	- 65
pH	- 5	- 5	- 5	- 5	- 10	- 15	- 20	- 15
C.O.D.	+150	+230	+310	+310	+230	+470	+530	+540
Turbidity	+130	+170	+170	+180	+190	+240	+280	+300
NO_2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
NO_3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
OPO_4	+140	+150	+160	+160	+360	+750	+970	+1390
TP	+110	+130	+140	+180	+320	+520	+680	+760
TKN	+ 40	+ 80	+140	+160	+140	+190	+240	+290
NH_3	+170	+210	+320	+350	+170	+290	+450	+570
S.S.	+ 10	+ 35	+ 55	+ 80	+ 75	+ 90	+ 95	+125
VNR	+ 75	+100	+110	+185	+165	+250	+245	+320
Chlorophyll a	- 90	-110	-130	-170	- 10	- 20	- 30	-160
Chlorophyll b	- 80	-100	-170	-140	- 80	-120	-170	-22-
Chlorophyll c	- 30	- 30	-120	-130	- 50	- 90	-110	-130
Phaeophytin	+140	+170	+200	+310	+120	+120	+250	+440

(i.e., events such as storms, which are readily documented), or by long term trends (i.e. overall degradation in water quality in the region). Therefore, the goal of baseline monitoring programs should be to obtain a sufficient data base to produce asymptotic MDIs and to allow the detection of only "true" impacts without an excessive number of "false alarms."

In order to demonstrate the effect of data base size and extent on statistical sensitivity, an example can be made of the data set from the December 1983 cruise. Due to ship time limitations, the Fall cruise in 1983 was not made until early December, a little over a month later than the Fall cruises made during 1981 and 1982. Possibly due to the later date or other natural causes, a number of the water quality parameters (C.O.D., TKN, phosphorous, and chlorophyll a) were at higher levels than previously observed for Fall. When the October 1981 data are used as the seasonal baseline in a MANOVA comparison with the December data set, an extremely high degree of statistical difference is noted ($P<0.0001$; multilvariate $F = 617$, d.f = 19, 52). A comparison of the canonical variate (c.v.) scores of the two data sets (Figure 7a) indicated that all of the December values were outside of the 99.9% probability limits of the October 1981 set (mean χ^2 is greater than 2000) (See Alden, 1984 for details of the probability limits evaluation procedure).

The 1981, 1982 and 1983 data sets were analyzed in a similar manner and plotted on the same c.v. score axis for comparison purposes (Figures 7b, c, d). The χ^2 values for the 99.9% baseline inclusion criteria for the December 1983 data set dropped dramatically as the data base is expanded: mean $\chi^2 = 7.52 \pm 0.04$ for the 1981 baseline; $\chi^2 = 0.75 \pm 0.02$ for 1981 and 1982; and $\chi^2 = 0.043 \pm 0.01$ for all three years combined. Although the MANOVA model still indicates differences ($F = 10.21$; d.f. = 19,472), the

Figure 7. Canonical variate scores for the December 1983 winter quality data and various baseline data sets: a) scores for December 1983 and October 1981 baseline data; b) scores for December 1983 and 1981 annual baseline data; c) scores for December 1983 and 1981-1982 composite baseline data; and d) scores for December 1983 and 1981-1983 composite baseline data (excluding December).



FREQUENCY (NUMBER OF CASES)
(a)
Fall 1981
Dec 83
DECEMBER 1983
BASELINE
BOTH
(b)
Baseline 1981
Dec 83
(c)
Baseline 1981-2
Dec 83
(d)
Baseline 1981-3
Dec 83
-40 -30 -20 -10 0 10 20 30 40
CANONICAL VARIATE SCORES
← COD, TKN, TP, Chlorophyll a

probability limits evaluation indicate that the December data set is not unreasonable for baseline conditions. Since the use of the probability limits chi-square test is probably the most appropriate evaluation tool for seasonal or baseline model comparisons (Alden, 1984) the December data set would not be considered to be "impacted," unless the trend continued on subsequent cruises.

Therefore, a data set exhibiting "natural" patterns of water quality would have been considered "impacted" if it had been encountered during trend assessment studies, and if the baseline had consisted of only one season or even one year of data. However, when the data base is expanded to include more of the "natural" variability encountered during a more extensive baseline monitoring program, the statistical "false alarm" is not sounded. Thus, the importance of a reasonably extensive data base is evident. The asymptotic MDIs may provide a set of criteria for determining when the data base is "extensive" enough. Obviously, the NDS baseline data base is approaching this level for certain of the less variable parameters.

SUMMARY AND CONCLUSIONS

A three year baseline water quality program was conducted at the proposed Norfolk Disposal Site beginning in 1981. The monitoring program was designed to develop a data base against which future water quality data can be evaluated once the site becomes active. The major goals of the program were threefold: 1) to provide a characterization of the natural water quality patterns at NDS; 2) to develop and continually update multivariate statistical models allowing the detection of future environmental trends which are significantly different from natural patterns; and 3) to estimate the minimum levels of statistically detectable change in each parameter (i.e.

MDI's) as a mechanism for the evaluation of the effectiveness of the program.

The water quality at the NDS appeared to be quite good and generally conformed to patterns previously observed. Most of the nutrients were quite low and many were below detection limits throughout most of the study. Seasonally, chlorophylls, organic load and most nutrients were low in the spring and high in the fall. Suspended solids and volatile residues were low in the winter and high in the summer, while dissolved oxygen, salinity and nutrients (particularly ammonia) followed the opposite pattern. A principle components analysis was employed to visually summarize these recurrent seasonal cycles.

The overall water quality was better than that reported for the more estuarine waters of Chesapeake Bay or the coastal waters of the New York Bight. Therefore, the region appears to be beyond the direct influence of many of man's activities.

The effects of depth, season and geographic location were statistically defined for each of the water quality parameters. There were often significant differences between surface and bottom measurements, although physical stratification due to temperature or salinity did not appear to restrict mixing processes to the point of ecological significance. For example, the oxygen content of the hypoliminion did not drop to levels that would prove detrimental ecologically; and the nutrients seldom showed strong patterns of stratification. Highly significant seasonal patterns were defined so that they can be taken into account in future trend assessment statistical models. On the other hand, differences between the water quality at NDS and that found in surrounding waters were seldom observed. When significant patterns were detected, closer investigation indicated that they were

probably caused by the influence of the Chesapeake Bay on the water quality of certain stations (particularly in the southwestern portion of the study area). Like the seasonal effects, predictable geographic patterns such as the plume-oceanic contrasts can be taken into account in the trend assessment models.

Minimum detectable impacts (MDI's) were calculated for each of the water quality parameters. All of the MDI's for the NDS water quality were of a moderate magnitude. As such, statistically significant changes would be expected to be detected before the absolute levels would become environmentally detrimental. Therefore, the monitoring program in combination with the statistical models would appear to provide an effective "early warning system" for the detection of any impacts which may be associated with disposal operations.

The effect of the size of a baseline data set on impact detection was explored. As a baseline is expanded from one season to one year, to multiple years, the MDI's increase rapidly at first then level off asymptotically. This pattern reflects the fact that more and more of the natural variability observed over time is being taken into account in the statistical models. The ultimate implication of this trend is that there should be a threshold baseline data set size so that irregular natural patterns are not considered to be "impacts." This effect was demonstrated using data from the NDS monitoring program. The NDS data base has revealed the threshold level for certain of the parameters, while it continues to approach it for others. Therefore, "false alarms" during future trend assignment studies would be expected to become even less likely as the data base is expanded by ongoing monitoring effects.

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